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PROSPECTUSES ON APPLICATION

THE MINERALOGICAL MAGAZINE

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No. 114. September, 1926. Vol. XXI.

COMMUNICATIONS FROM THE CRYSTALLOGRAPHIC LABORATORY OF THE UNIVERSITY OF MANCHESTER, No. 4.

The anomalous optical properties of some new series of isomorphous double tartrates.

By HAROLD E. BUCKLEY, M.Sc.
Assistant Lecturer in Crystallography.

[Read June 15, 1926.]

IN a previous paper[1] two well-known crystalline compounds, sodium-potassium tartrate, $NaKC_4H_4O_6 . 4H_2O$, and sodium-ammonium tartrate, $Na(NH_4)C_4H_4O_6 . 4H_2O$, were described, and it was therein shown how, in the crystals obtained by mixing these two isomorphous substances in any proportion, the dispersions of the optic axes in the freshly prepared crystals were incompatible with orthorhombic symmetry. The crystals have been frequently measured and found to be orthorhombic bisphenoidal in external symmetry and this has been further confirmed by the author's measurements. A full description of all the various dispersions to be found in the orthorhombic and monoclinic systems may be obtained from any text-book of crystallography, but in the following pages two of these are specially important. These are crossed dispersion,

[1] H. E. Buckley, Some anomalous optical properties of freshly-prepared mixed crystals of the Seignette salts. Min. Mag., 1924, vol. 20, pp. 159–172.

as exemplified in borax, and belonging to monoclinic crystals; and crossed axial-plane dispersion, an example of which is given by brookite, and proper to the orthorhombic classes of symmetry.

Crystals of the mixed tartrates when freshly prepared almost invariably possessed a dispersion of the borax type, though this is only consistent with monoclinic symmetry. A description of the outward appearance of these crystals is given in the previous paper. The interference-figures are nearly always to be seen through the cleavage section parallel to (001). Only in crystals which possess less than 5% $Na(NH_4)C_4H_4O_6 . 4H_2O$ in the series described does the acute bisectrix emerge parallel to the a-axis, so that sections require to be cut parallel to (100). Only when the crystals have stood for a long time after preparation, or have been heated sufficiently long, do the interference-figures resemble that afforded by brookite or by sodium-ammonium tartrate. In the latter case, all optic axes for different colours are alined in one plane, (100), but there is a strong dispersion of the optic axes. In the former case there is one colour in the visible spectrum for which the crystal is optically uniaxial, while for colours closer to the red end of the spectrum the optic axes all lie in the (100) plane, and for colours closer to the violet end they all lie in the (010) plane.

When, however, the crystals are fresh, the dispersion is of the borax type, with the optic axial plane for deep-red nearly parallel to (100), while the remaining optic axial planes are spread out like the rays of a fan, giving as values for the total dispersions from red to violet light of from 5° to 75°. On standing, all crystals show a change of interference-figure to either the brookite type or the normal type (sodium-ammonium tartrate) of orthorhombic dispersion. When this change in optic axial plane directions is taking place a change in optic axial angles is also taking place, there being in some cases a widening, and in other cases a contraction, of optic axial angle. Measurements on any of these crystals are therefore liable to differ, according to whether they take place when the crystals are freshly prepared or after these have been allowed to stand for some time.

Fig. 1 shows a photograph of the interference-figure of a section of a crystal having the composition $50\ NaKC_4H_4O_6 . 4H_2O + 50Na(NH_4)C_4H_4O_6 . 4H_2O$, taken in the light of the mercury-arc. An inspection will show that it appears to consist of two superimposed interference-figures. One of these is due to the 5461 line in the green and is symmetrically disposed about the eyepiece cross-wires; the other and stronger figure is that due to the 4358 line in the violet and is set at an angle of about 73°

to the other figure. The excessive actinic power of the violet light has caused the interference-figure for violet to preponderate in spite of the fact that a green filter was used at the time of the exposure. With crystals of this composition, careful measurements of the optic axial angles were made on the Hutchinson universal goniometer and the results were recorded in Table IX, p. 171, of the previous paper. They are for convenience again given in Table I *a* (p. 66) of the present paper. After three years' standing, sections of the same crystals were taken and measured, and the results are given in Table I *b*. A glance at Tables I *a* and I *b* will show that the results of this method of measuring optic axial angles support the conclusions arrived at with the more rapid, but not so accurate, method of the micrometer eyepiece used in tabling the other results given in this paper; viz. that there is a definite change in the optic axial angle for light of each wave-length as well as a re-adjustment of optic axial planes.

FIG. 1. Interference-figure showing crossed dispersion.

The crossed dispersion shown by freshly prepared crystals is of two types:

(*A*) The optic axial plane for deep-red is very nearly (within 1° or 2°) parallel to (100), and the violet end of the spectrum shows greater sensitivity to change in optic axial plane (fig. 2).

(*B*) The optic axial plane for the extreme violet is almost parallel to (010) and there is a greater spread of the optic axial planes in the red end of the spectrum (fig. 3).

The series $\{m\text{NaK}, n\text{Na}(\text{NH}_4)\}\text{C}_4\text{H}_4\text{O}_6 . 4\text{H}_2\text{O}$ described in the previous paper belong to both these types, mixed crystals with a greater proportion of the NaK tartrate belonging to type *B* and those with less to type *A*. Mixed crystals of the series $\{m\text{KNa}, n\text{K}(\text{NH}_4)\}\text{C}_4\text{H}_4\text{O}_6 . 4\text{H}_2\text{O}$ all belong to type *B*, while those of the series $\{m(\text{NH}_4)\text{Na}, n(\text{NH}_4)\text{K}\}$ are all of the type *A*.

In the present paper the author has prepared for optical examination a large number of compounds obtained by the neutralization of tartaric acid with the same three bases, Na, K, and NH_4, and has obtained results

which considerably enlarge the number of mixtures which may strictly be called isomorphous with the original Seignette salt, $NaKC_4H_4O_6 . 4H_2O$, and which form series closely resembling in form and properties the

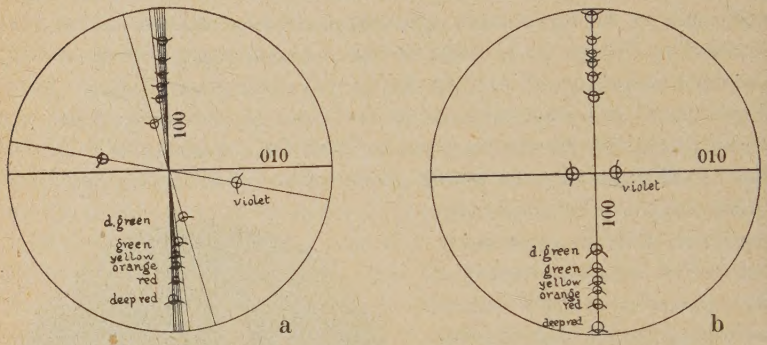


FIG. 2. Optic axes for different colours in mixed crystals $\{50(NH_4)Na, 50(NH_4)K\}C_4H_4O_6 . 4H_2O$.

(*a*) crossed dispersion (borax type *A*) in freshly prepared crystals;
(*b*) crossed axial-plane dispersion (brookite type) in the final state.

(See Table III *b*, p. 68.)

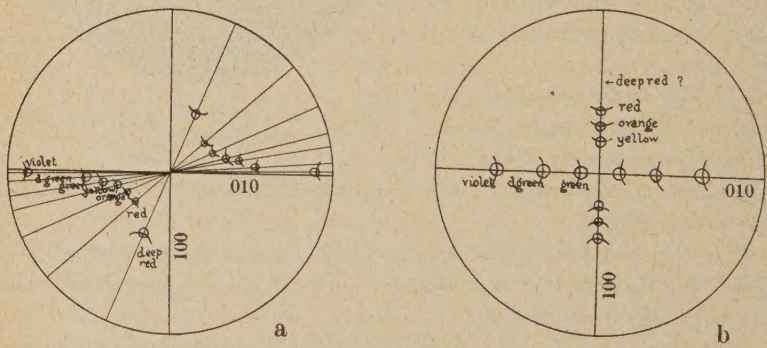


FIG. 3. Optic axes for different colours in mixed crystals $\{20KNa, 80K(NH_4)\}C_4H_4O_6 . 4H_2O$.

(*a*) crossed dispersion (borax type *B*) in freshly prepared crystals;
(*b*) crossed axial-plane dispersion (brookite type) in the final state.

(See Table II *a*, p. 66.)

series studied in the previous paper. The latter series was composed of mixtures of the type $\{m\text{NaK}, n\text{Na}(NH_4)\}C_4H_4O_6 . 4H_2O$. Other possible variations of all three bases with tartaric acid are $\{m\text{KNa}, n\text{K}(NH_4)\}$

$C_4H_4O_6 . 4H_2O$ and $\{m(NH_4)Na, n(NH_4)K\}C_4H_4O_6 . 4H_2O$, and members of both these series have been prepared and their optical properties studied in a similar way to those of the first series. The results are included in the present paper. In addition, the possible variations of *two* of the three bases Na, K, and NH_4 with tartaric acid have been studied, and the following series of isomorphous mixtures, similar to the foregoing, have been found capable of preparation.

$\{mNa_2, nNa(NH_4)\}C_4H_4O_6 . 4H_2O$ and $\{m(NH_4)_2, n(NH_4)Na\}C_4H_4O_6 . 4H_2O$;
$\{mNa_2, nNaK\}C_4H_4O_6 . 4H_2O$ and $\{mK_2, nKNa\}C_4H_4O_6 . 4H_2O$.

On the other hand, it was not found possible to prepare any member of the two related series $\{m(NH_4)_2, n(NH_4)K\}C_4H_4O_6 . 4H_2O$ and $\{mK_2, nK(NH_4)\}C_4H_4O_6 . 4H_2O$.

Observations on the new series of Seignette salts in which all three bases Na, K, *and* NH_4 *are present.*

The results obtained in the study of these mixtures are given in some detail in the following pages. It should be understood that, unless specially mentioned, the acute bisectrix is always parallel to the *c*-axis and the sign of birefringence negative.

Series $\{m$KNa, nK$(NH_4)\}C_4H_4O_6 . 4H_2O$.—Crystals belonging to members of this series were readily obtained, but when containing a large proportion of ammonium base they showed a tendency to effloresce rather more quickly than usual on exposure to air. In the preparation, too, of the latter crystals, the solution itself had to be kept saturated with ammonia vapour; otherwise needle-like crystals of lower symmetry, and not related to these series, were obtained. Tables II *a*, II *b*, II *c*, and II *d* relate to observations made upon this series where $m=20$, $33\frac{1}{3}$, 50, and $66\frac{2}{3}$ per cent. respectively. From a perusal of these tables it will readily be seen that this series presents optically anomalous properties similar to the series described in the first paper. There is a similar rise to a maximum value of initial crossed dispersion, and the process of changing to the final state, in harmony with the orthorhombic symmetry of the crystal-angles, is similarly hastened by heating. There is, however, one striking difference. The optic axial planes in the brookite type of dispersion are always (100) for red and (010) for violet light. When the dispersion is of the normal type, i.e. when all the optic axes lie in a single plane, this is (100) in the series already described in the first paper and in most of the subsequent series, but in this particular series, $\{m$KNa, nK$(NH_4)\}C_4H_4O_6 . 4H_2O$, the optic axial plane is (010).

Series $\{m(NH_4)Na, n(NH_4)K\}C_4H_4O_6 . 4H_2O$.—Crystals belonging to this type of mixture are very readily prepared, and large clear crystals may be obtained more frequently than is the case with most other series. The cleavage parallel to (001) which exists to a greater or lesser degree in all members of the different series is here exceptionally good and enables sections for the study of the optical properties to be obtained readily. The results of observations on members of this series are shown in Tables III *a*, III *b*, and III *c*. From these it is seen that a precisely similar set of phenomena to those observed in the two previously described series take place. These include, (*a*) an initial crossed dispersion of the borax type which gradually settles down to an orthorhombic form of dispersion, and (*b*) a change in optic axial angle for any colour after an interval of time has elapsed.

Heating, as in all previous instances, hastens the settling-down process. It will be seen from Table III *b* that when readings of the crossed dispersion are taken in an intermediate stage in the process of settling down there is a preliminary movement of the optic axial planes. In this instance, all planes from the red end of the spectrum to Hg-green have closed up into alinement with the optic axial plane for red, but the total angle of crossed dispersion, from red to violet, has remained unchanged. There is a subsequent movement of optic axial planes for the violet end of the spectrum into a position at right angles to the optic axial plane for red. Difficulty was experienced with mixtures containing a larger proportion of $(NH_4)KC_4H_4O_6 . 4H_2O$, since, after the heating process had taken place, the sections rapidly became opaque and readings were found to be possible only in the case of the more monochromatic sources of light. This fact accounts for the shortness of Table III *c*.

Observations on the new series of Seignette salts in which two *of the three bases* NH_4, Na, *and* K *are present.*

The actual preparation of members of these series mentioned above as possible was not difficult. The crystals themselves are identical in habit and in general appearance with crystals of the three foregoing series (which contain all three bases NH_4, Na, and K). An examination of the interference-figures of sections cut from these crystals shows that although there is a strong dispersion of the optic axes for colours in the visible spectrum, no trace of the anomalous crossed dispersion of the borax type was found to be present, though subsequent movements of the optic axes themselves was traced all through the different series. The results for crystals of the series $\{m(NH_4)_2, n(NH_4)Na\}C_4H_4O_6 . 4H_2O$ are given

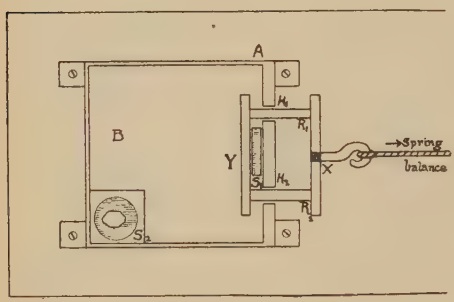
in Tables IV *a*, IV *b*, and IV *c*, and those for the series $\{m\mathrm{Na}_2, n\mathrm{Na}(\mathrm{NH}_4)\}\mathrm{C}_4\mathrm{H}_4\mathrm{O}_6 . 4\mathrm{H}_2\mathrm{O}$ in Tables V *a*, V *b*, and V *c*. The interference-figures afforded by sections of crystals in these two series (neither of which contains potassium) are similar in that there is a very strong, though apparently normal, dispersion of the optic axes for the different colours. This may amount to as much as 50° (Table V *a*) between the optic axial angles for visible red and visible violet. It is possible, therefore, that there may be an anomalous crossed dispersion in these two series, similar to that observed in all previous series, except that it will occur in the region near the end of the visible spectrum or perhaps just beyond in the ultra-violet, so that, on settling down to the final state, the uniaxial point will be located a little beyond the point where visible observation is possible. Evidence is shown in all the tables that there is a change in optic axial angle for the different colours after a lapse of time.

The remaining two series which were found to be readily prepared are $\{m\mathrm{K}_2, n\mathrm{KNa}\}\mathrm{C}_4\mathrm{H}_4\mathrm{O}_6 . 4\mathrm{H}_2\mathrm{O}$ and $\{m\mathrm{Na}_2, n\mathrm{NaK}\}\mathrm{C}_4\mathrm{H}_4\mathrm{O}_6 . 4\mathrm{H}_2\mathrm{O}$. The results obtained from these are shown in Tables VI *a*, VI *b*, and VI *c*. In all cases the main characteristics of the interference-figures are the wide angle of the optic axes, rendering measurements difficult, and the fact that, like the two immediately foregoing series, no trace of crossed dispersion in the initial state of the crystals was observed. The dispersion of the optic axes, in sharp contrast to all the previously described crystals, is somewhat weaker.

Effect of pressure on the rate of settling down of the crystals.

In the previous paper allusion was made to the fact that an increase of temperature has the effect of hastening considerably the process of settling down to the final state in these series of crystals. Experiments have been performed on a compound of the composition $\{80(\mathrm{NH}_4)\mathrm{Na}, 20(\mathrm{NH}_4)\mathrm{K}\}\mathrm{C}_4\mathrm{H}_4\mathrm{O}_6 . 4\mathrm{H}_2\mathrm{O}$, already described in Table III *a*, to determine the effect of pressure on the rate of change which takes place. This particular compound was chosen because it possessed a large initial angle of crossed dispersion and is therefore more sensitive to any slight variation of the rate of settling down that might be introduced by the application of pressure on the section. The effect of pressure was observed in the following manner. Two sections were cut from freshly prepared crystals and the crossed dispersion measured at once. They were then exposed to a temperature somewhat above the ordinary, so that the whole process of settling down could be more quickly brought about. One of them was

then compressed while the other remained free, and after a suitable interval of time had elapsed measurements were again made on both sections and the differences noted. Pressure was applied normally to the section in a covering of undiluted Canada balsam, which, while keeping the section away from the air, remained fluid, so that the pressure was not interfered with. The arrangement used is shown in fig. 4. A brass box B is reinforced on one side A, and the latter is pierced by two holes H_1 and H_2. One section S_2 is placed in a remote corner of the box and the other section S_1 is compressed between the thicker wall of the box and a flat brass strip Y connected to a second brass strip X outside the



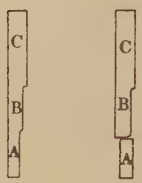


Fig. 4. Fig. 5 *a*. Fig. 5 *b*.

Fig. 4. Apparatus for applying pressure to crystal-sections.
Fig. 5. Side-view of crystal-section (Table VII *b*, p. 71).

box by means of two brass rods R_1 and R_2, which pass through the holes H_1 and H_2 in the box. A hook attached to the outer brass strip X connects the arrangement to a spring-balance, by means of which the pressure may be regulated. The whole arrangement is mounted on a board which can be moved into an asbestos-lined wooden box provided with air outlet-holes and heated to the required temperature by a set of filaments.

No results were obtained for pressures of from 1 to 5 lb. With pressures of from 10 to 15 lb. definite effects were recorded. These are included in Tables VII *a* and VII *b*, and show that pressure has a *retarding* effect on the rate of settling down of these crystals. The section used in the experiment recorded in Table VII *b* is shown in side-elevation in figs. 5 *a* and 5 *b*. Fig. 5 *a* shows the original outline of the section as cleaved. It was step-like in shape and consisted of three portions *A*, *B*,

and *C*. Each portion gave identical values of initial crossed-dispersion, &c., and the interference-figures observed were exceptionally clear and sharp, so that re-grinding of the lower surface was not resorted to. On the application of pressure the thinnest portion *A* broke off and was shielded from the compressing influence by the thick portion *C*, while the middle portion *B* only received part of the pressure. Table VII *b* shows that the uncompressed section S_2 on re-examination after heating to 42° C. for one day has still a crossed dispersion of 5°. The shielded part of the compressed section, shown in fig. 5 *b*, has also a crossed dispersion of 5°, while the fully compressed part *C* has been retarded to 12° of crossed dispersion and the intermediate portion *B* to $7\frac{1}{2}$°. There is no doubt, therefore, that pressure has a definite influence on the rate of settling down of these crystals and that this is a retardation, as opposed to the accelerating influence of an increase in temperature. Neither pressure nor temperature has any effect on the final state when this is arrived at, for then all crystals of the same composition, no matter in what way the final state has been reached, possess identical optical properties.

Homogeneity of crystals exhibiting anomalous optical properties.

In order to ascertain whether the crystals used in these experiments suffered any change in composition while growing in solution or whether they remained homogeneous throughout, a special experiment was made, using the mixed crystals of the same composition as in the pressure experiment, viz. $\{80(NH_4)Na, 20(NH_4)K\}C_4H_4O_6.4H_2O$. All results previously recorded were obtained from sections which actually included the basal planes (001) of the crystals. No observations have been so far recorded of sections drawn from the central portions of the crystals. The author, however, has made many observations on sections taken from the middle of crystals and has invariably found that the crossed dispersion, when this occurred, and also the optic axial angles in freshly prepared crystals differed appreciably from those in a terminal (001) section (Table VIII *a*). From this it might at first be supposed that the composition of the mixture was varying with the crystal-growth. When, however, the sections from the middle portion of a crystal were heated until the final state was reached, it was found that the optical properties were then absolutely identical with those of the terminal sections. This makes it reasonable to suppose that there is homogeneity of composition throughout the growth of these crystals. The interior portion was in

contact with the warm solution in the earlier stages of growth and then probably exhibited the same crossed dispersion as is found in the terminal sections of the same crystal when growth has finished. In the meantime, while further growth is taking place, the earlier terminal section is now inside the crystal and has suffered a partial change towards the final state through being heated for some hours longer than that which is the terminal section of the crystal when growth has finished. Further heating brings interior and exterior portions of the crystal to the same final state.

Location of the seat of change in the molecule.

The above results simply indicate that somewhere in the packing together of the crystal-units there is an initial disturbance or strain, possibly due to some spatial difficulty of fitting in, in so short a time, the complex molecules of two or more different shapes and sizes. Since no observable variation in crystal-angles has been observed in any of these cases, the seat of the strain is most probably in some region of minor importance. To obtain the complete set of anomalous phenomena, viz. crossed dispersion and change in optic axial angle on standing, it appears necessary that all three bases, NH_4, Na, and K, must be present, though the data do not rule out the possibility of the complete set of phenomena taking place in the ultra-violet region in those crystals that contain NH_4 and Na only. The alteration of optic axial angle on standing is a phenomenon which is characteristic of the whole series. To penetrate further into the structure X-ray examination of the crystals will be necessary, both before and after the changes have taken place.

The directions in which the strains may be set up are, from the changes studied in these papers, limited to those which are proper to the monoclinic system; and more probably to those space-groups which can be arrived at by taking the orthorhombic holoaxial space-groups, on which the structure of the crystals in the final state must depend, and eliminating two of the axes of symmetry but leaving the third. Three possible space-groups are then involved, viz. C_2^1, C_2^2, and C_2^3. Further than this it is not at present possible to speculate.

Summary.

I. In addition to the isomorphous series of mixed crystals studied in the first paper, and having the general composition $\{m\,NaK, n\,Na(NH_4)\}$ $C_4H_4O_6 . 4H_2O$, the same three bases can unite to form the series

$\{m\,\mathrm{KNa}, n\mathrm{K(NH_4)}\}\mathrm{C_4H_4O_6}\,.\,4\mathrm{H_2O}$ and $\{m\mathrm{(NH_4)Na}, n\mathrm{(NH_4)K}\}\mathrm{C_4H_4O_6}\,.\,4\mathrm{H_2O}$. Further, there are four other series found to be possible, in which only *two* of the bases $\mathrm{NH_4}$, Na, and K are united with the acid. These are of the general type

$\{m\mathrm{Na_2}, n\mathrm{Na(NH_4)}\}\mathrm{C_4H_4O_6}\,.\,4\mathrm{H_2O}$ and $\{m\mathrm{(NH_4)_2}, n\mathrm{(NH_4)Na}\}\mathrm{C_4H_4O_6}\,.\,4\mathrm{H_2O}$;
$\{m\mathrm{Na_2}, n\mathrm{NaK}\}\mathrm{C_4H_4O_6}\,.\,4\mathrm{H_2O}$ and $\{m\mathrm{K_2}, n\mathrm{KNa}\}\mathrm{C_4H_4O_6}\,.\,4\mathrm{H_2O}$.

All these series are isomorphous with each other, and are similar in habit and cleavage.

II. In the series which contain all three substituents $\mathrm{NH_4}$, Na, and K the following effects are to be observed:

(*a*) Initial crossed dispersion of the optic axial planes, with subsequent changes to a normal orthorhombic dispersion or to a crossed axial-plane dispersion of the brookite type.

(*b*) A change in optic axial angles for different colours of the spectrum as the crystals settle down to the final state. In crystals which contain only two of the substituent bases $\mathrm{NH_4}$, Na, and K only the second (*b*) of these effects is invariably present.

III. In basal sections of the freshly prepared crystals, the greatest optical anomalies are exhibited by the terminal sections, and as the distance from the surface increases the anomalous effects fall off in magnitude. All sections, whether terminal or otherwise, ultimately possess the same optical properties when the crystals have reached the final state. This may be considered as evidence in favour of the homogeneity of these crystals.

IV. A rise in temperature hastens considerably in these crystals the process of settling down to the final state. Application of pressure, normal to the section, has a contrary effect. In neither case is there any effect on the final state when this is ultimately reached.

V. The strains involved degrade the symmetry of the freshly prepared crystals to that of a monoclinic class. Externally, however, judging from a large number of angular measurements, the crystals appear to be still orthorhombic holoaxial, and there is no corresponding readjustment of angular values as the settling down process in the interior takes place.

The author desires to take this opportunity of thanking Sir Henry Miers for his kind interest throughout this work and for helpful advice on many occasions.

TABLE I *a*. $\{50NaK, 50Na(NH_4)\}C_4H_4O_6.4H_2O$.

Colour	Red (6,500 Å.U. ca.).	Hg-yellow.	Hg-green.	Hg-violet.[1]
2E of freshly prepared crystals ...	69° 10′	56° 2′	45° 4′	54° 40′
Angle of crossed dispersion ...		4°	8°	61°

Total = 73°

TABLE I *b*. $\{50NaK, 50Na(NH_4)\}C_4H_4O_6.4H_2O$.

Colour	Red (6,500 Å.U. ca.).	Hg-yellow.	Hg-green.	Hg-violet.
2E in final state ...	73° 29′	62° 49′	55° 35′	40° 32′
Optic axial plane ...		(100)		(010)

TABLE II *a*. $\{80K(NH_4), 20KNa\}C_4H_4O_6.4H_2O$. (See fig. 3.)

	Crossed dispersion of freshly prepared crystals.		2E of freshly prepared crystals.
Deep-red to red[2] ...	25½°	Total, 66°	Deep-red ... 43°
Red to orange	16½		Red 30½
Orange to Hg-yellow ...	10		Orange 32
Hg-yellow to Hg-green	5		Hg-yellow ... 38
Hg-green to deep-green	5½		Hg-green ... 46
Deep-green to Hg-violet	3½		Deep-green ... 56
			Hg-violet ... 84

Equilibrium was reached after heating the sections for 4 days to 37° C., and the following readings were then obtained:

	2E in final state.	Optic axial plane.
Deep-red ...	good reading not obtained	
Red	42½°	... ... (100)
Orange	33	
Hg-yellow	23	
Hg-green	14	
Deep-green	38	... ... (010)
Hg-violet	64	

[1] The mercury-arc spectrum consists of lines of the following wave-lengths:

Red	6,152 and 6,232 Å.U.	(weak).
Yellow	5,770 and 5,791 ,,	(intense).
Green	5,461 ,,	(intense).
Blue	4,916 ,,	(weak).
Violet	4,358 ,,	(intense).
Deep-violet ...	4,047 and 4,078 ,,	(weak).

The three lines of sufficient intensity to be of use in this work and which can be isolated by means of suitable filters are the yellow, green, and violet (indicated above as intense).

[2] In addition to the colours obtained from the mercury-arc shown in Table I, the following approximate colour-filters were used: deep-red (λ = 7,000 Å.U. ca.),

TABLE II *b*. $\{66\frac{2}{3}K(NH_4), 33\frac{1}{3}KNa\}C_4H_4O_6 . 4H_2O$.

Crossed dispersion of freshly prepared crystals.			2E of freshly prepared crystals.	
Deep-red to red	25°	Total, 50°	Deep-red ...	32°
Red to orange	10		Red	35
Orange to Hg-yellow ...	3		Orange	41
Hg-yellow to Hg-green	5		Hg-yellow ...	45
Hg-green to deep-green	5		Hg-green ...	54
Deep-green to Hg-violet	2		Deep-green ...	57
			Hg-violet ...	74

After heating the sections for 4 days at 37° C., equilibrium was obtained, with the following results:

	2E in final state.	Optic axial plane.
Deep-red ...	good reading not obtained	
Red	32°	... ... (100)
Orange	23	
Hg-yellow	14	
Hg-green	25	
Deep-green	$38\frac{1}{2}$	... ... (010)
Hg-violet	64	

TABLE II *c*. $\{50K(NH_4), 50KNa\}C_4H_4O_6 . 4H_2O$.

Crossed dispersion of freshly prepared crystals.			2E of freshly prepared crystals.	
Deep-red to red ...	11°	Total, 17°	Deep-red ...	43°
Red to orange	$1\frac{1}{2}$		Red	52
Orange to Hg-yellow ...	1		Orange	59
Hg-yellow to Hg-green	1		Hg-yellow ...	62
Hg-green to deep-green	$1\frac{1}{2}$		Hg-green ...	66
Deep-green to Hg-violet	1		Deep-green ...	74
			Hg-violet ...	104

After heating the sections for 4 days at 35°C., the following equilibrium readings were obtained:

	2E in final state.	Optic axial plane.
Deep-red	10°	... ... (100)
Red	34	
Orange	44	
Hg-yellow	50	
Hg-green	58	... ... (010)
Deep-green	66	
Hg-violet	82	

red (λ = 6,500 Å.U. ca.), orange (λ = 6,000 Å.U. ca.), deep-green (λ = 5,000 Å.U. ca.).

TABLE II *d*. $\{33\frac{1}{3}K(NH_4), 66\frac{2}{3}KNa\}C_4H_4O_6.4H_2O$.

Crossed dispersion of freshly prepared crystals: Deep-red to Hg-violet (total) = 5°. This was found to disappear in about a week even at ordinary temperatures. The optic axial angles were then found to have the following values:

	2E in final state.	Optic axial plane.
Deep-red	?	
Red	67°	
Orange	$70\frac{1}{2}$	
Hg-yellow	76	... (010)
Hg-green	83	
Deep-green	90	
Hg-violet	>116 (just off edge of field)	

TABLE III *a*. $\{80(NH_4)Na, 20(NH_4)K\}C_4H_4O_6.4H_2O$.

	Crossed dispersion of freshly prepared crystals.		2E of freshly prepared crystals.	
Deep-red to red ...	$\frac{1}{2}$°	Total, $35\frac{1}{2}$°	Deep-red ...	94°
Red to orange	$\frac{1}{2}$		Red	87
Orange to Hg-yellow ...	0		Orange	80
Hg-yellow to Hg-green	$\frac{1}{2}$		Hg-yellow ...	68
Hg-green to deep-green	$1\frac{1}{2}$		Hg-green ...	57
Deep-green to Hg-violet	$32\frac{1}{2}$		Deep-green ...	34
			Hg-violet ...	$18\frac{1}{2}$

The sections attained equilibrium after heating for 4 days at 37° C., when the following results were obtained:

	2E in final state.	Optic axial plane.
Deep-red	104°	
Red	91	
Orange	84	
Hg-yellow	80	... . (100)
Hg-green	74	
Deep-green	$64\frac{1}{2}$	
Hg-violet	35	

TABLE III *b*. $\{50(NH_4)Na, 50(NH_4)K\}C_4H_4O_6.4H_2O$. (See fig. 2.)

	Crossed dispersion of freshly prepared crystals.		2E of freshly prepared crystals.	
Deep-red to red ...	1°	Total, 77°	Deep-red ...	78°
Red to orange	$\frac{1}{2}$		Red	69
Orange to Hg-yellow ...	$\frac{1}{2}$		Orange	62
Hg-yellow to Hg-green	2		Hg-yellow ...	56
Hg-green to deep-green	10		Hg-green ...	49
Deep-green to Hg-violet	63		Deep-green ...	34
			Hg-violet ...	46

After heating to 32° C. for 3 days the crystals were in an intermediate stage of the settling-down process and gave the following results :

	Crossed dispersion of crystals in intermediate stage.	
Deep-red to red	0°	Total, 77° (as at first).
Red to orange	0	
Orange to Hg-yellow	0	
Hg-yellow to Hg-green	0	
Hg-green to deep-green	2	
Deep-green to Hg-violet	75	

After a total heating of 6 days at 32° C., the final state of the crystals was reached and is shown by the following figures :

	2E in final state.	Optic axial plane.
Deep-red	89°	
Red	79	
Orange	73	
Hg-yellow	69	(100)
Hg-green	62	
Deep-green	52	
Hg-violet	13	(010)

TABLE III *c*. $\{20(NH_4)Na, 80(NH_4)K\}C_4H_4O_6 . 4H_2O$.

	Crossed dispersion of freshly prepared crystals.		2E of freshly prepared crystals.	
Deep-red to Hg-yellow	9°	Total, 51°	Deep-red	67°
Hg-yellow to Hg-green	3½		Hg-yellow	61
Hg-green to Hg-violet	38½		Hg-green	56
			Hg-violet	51½

The following figures from the interference-figures in the final state of the crystals were obtained after heating for 4 days to 37° C. :

	2E in final state.	Optic axial plane.
Deep-red	62°	
Hg-yellow	53	(100)
Hg-green	45	
Hg-violet	44	(010)

TABLE IV *a*. $\{33\frac{1}{3}(NH_4)_2, 66\frac{2}{3}(NH_4Na)\}C_4H_4O_6 . 4H_2O$.

	2E of freshly prepared crystals.	2E after heating to 37° C. for 4 days.
Deep-red	98°	95°
Hg-yellow	90	88
Hg-green	84	82
Hg-violet	50	48½

Optic axial plane throughout is (100).

TABLE IV *b*. $\{50(NH_4)_2,50(NH_4)Na\}C_4H_4O_6 . 4H_2O$.

	2E of freshly prepared crystals.	2E after heating to 35° C. for 4 days.
Deep-red	90°	94°
Hg-yellow	87½	91
Hg-green	83	85
Hg-violet	48	51½

Optic axial plane throughout is (100).

TABLE IV *c*. $\{66\frac{2}{3}(NH_4)_2,33\frac{1}{3}(NH_4)Na\}C_4H_4O_6 . 4H_2O$.

2E of freshly prepared crystals.

Deep-red, Hg-yellow, Hg-green: beyond field of view

Hg-violet: 116° (edge of field)

Accurate measurements of changes in crystals of this composition could not be obtained on account of the wideness of the optic axial angles. The optic axial plane, as before, is (100).

TABLE V *a*. $\{33\frac{1}{3}Na_2,66\frac{2}{3}(NH_4)Na\}C_4H_4O_4 . 4H_2O$.

	2E of freshly prepared crystals.	2E after heating to 37° C. for 4 days.
Deep-red	100°	101°
Hg-yellow	92	90
Hg-green	85	83½
Hg-violet	50	51

Optic axial plane throughout is (100).

TABLE V *b*. $\{50Na_2,50Na(NH_4)\}C_4H_4O_6 . 4H_2O$.

	2E of freshly prepared crystals.	2E after heating to 35° C. for 4 days.
Deep-red	105°	105°
Hg-yellow	92	91
Hg-green	84	85
Hg-violet	50	51

Optic axial plane throughout is (100).

TABLE V *c*. $\{66\frac{2}{3}Na_2,33\frac{1}{3}Na(NH_4)\}C_4H_4O_6 . 4H_2O$.

	2E of freshly prepared crystals.	2E after heating to 37° C. for 4 days.
Deep-red	91°	95°
Hg-yellow	89	92
Hg-green	82½	85
Hg-violet	49½	52

Optic axial plane throughout is (100).

TABLE VI *a*. $\{33\frac{1}{3}K_2.66\frac{2}{3}KNa\}C_4H_4O_6.4H_2O$.

	2E of freshly prepared crystals.	
Deep-red	out of field	Optic axial plane (010); acute bisectrix ⊥ (100); optical sign positive.
Hg-yellow	... 115° ±	
Hg-green	... 108	
Hg-violet	... $86\frac{1}{2}$	

TABLE VI *b*. $\{50K_2,50KNa\}C_4H_4O_6.4H_2O$.

	2E of freshly prepared crystals.	
Deep-red	out of field	Optic axial plane (010); acute bisectrix ⊥ (100); optical sign positive.
Hg-yellow ...		
Hg-green... ...		
Hg-violet...	... 94°	

TABLE VI *c*. $\{50Na_2,50NaK\}C_4H_4O_6.4H_2O$.

	2E of freshly prepared crystals.	
Deep-red ...	out of field	optic axial plane (010); acute bisectrix ⊥ (100); optical sign positive.
Hg-yellow ...		
Hg-green... ...		
Hg-violet...	116° ± (edge of field)	

TABLE VII *a*. Pressure experiment.

Crossed dispersion in freshly prepared crystals.	Temperature, and duration of pressure.	Pressure on section.	Crossed dispersion in section heated but not compressed.	Crossed dispersion in section both heated and compressed.
$35\frac{1}{2}$°	20°C. for 24 hours	10 lb.	25°	29°
$35\frac{1}{2}$°	37°C. for 48 hours	15 lb.	11°	17°

TABLE VII *b*. Pressure experiment.

In this experiment the temperature was 42° C. and the pressure of 15 lb. was applied for 24 hours. The following figures show the effect obtained:

Crossed dispersion in freshly prepared crystals.	Crossed dispersion in section heated but not compressed.	Crossed dispersion in portion of section shielded from pressure (*A*, fig. 5).	Crossed dispersion in portion of section partly shielded from pressure (*B*, fig. 5).	Crossed dispersion in section heated and compressed.
$35\frac{1}{2}$°	5°	5°	$7\frac{1}{2}$°	12°

TABLE VIII *a*. Homogeneity experiment.

a. In terminal sections:

	Crossed dispersion of freshly prepared crystals.		2E of freshly prepared crystals.	
Deep-red to red ...	$\frac{1}{2}°$	Total, $35\frac{1}{2}°$	Deep-red ...	94°
Red to orange	$\frac{1}{2}$		Red	87
Orange to Hg-yellow ...	0		Orange	80
Hg-yellow to Hg-green	$\frac{1}{2}$		Hg-yellow ...	68
Hg-green to deep-green	$1\frac{1}{2}$		Hg-green ...	57
Deep-green to Hg-violet	$32\frac{1}{2}$		Deep-green ...	34
			Hg-violet ...	$18\frac{1}{2}$

β. In sections cut at a distance from terminal (001) faces of 1 cm.:

	Crossed dispersion in freshly prepared crystals.		2E of freshly prepared crystals.	
Deep-red to red	0°	Total, 10°	Deep-red ...	96°
Red to orange	0		Red	89
Orange to Hg-yellow ...	1		Orange	81
Hg-yellow to Hg-green...	0		Hg-yellow ...	79
Hg-green to deep-green	1		Hg-green ...	71
Deep-green to Hg-violet	8		Deep-green ...	62
			Hg-violet ...	32

TABLE VIII *b*. Homogeneity experiment.

	2E in final state of both sets of sections *a* and *β*.	
Deep-red	104°	Optic axial plane (100)
Red	91	
Orange	84	
Hg-yellow	80	
Hg-green	74	
Deep-green	$64\frac{1}{2}$	
Hg-violet	35	

On some chloritic minerals associated with the basaltic Carboniferous rocks of Derbyshire.

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[Read June 15, 1926.]

THE occurrence of chloritic minerals as infillings of vesicular cavities in volcanic rocks is very common in rocks of all geological ages. Numerous chlorites have been described and analysed, but their classification and nomenclature are complicated by the fact that, as in the case with other hydrous alumino-silicates such as zeolites and clay minerals, the chlorites present a great variety of chemical compounds, usually of indefinite composition.

M. F. Heddle,[1] whose work on Scottish minerals is so very extensive, was the first to attempt the classification of chlorites according to their genesis. His classification is as follows:

(1) Chlorites—usually markedly crystalline, not decomposed by hydrochloric acid, principally occurring in metamorphic and sedimentary rocks.

(2) Saponites—usually cryptocrystalline or amorphous, readily decomposed by hydrochloric acid, occurring as products of decomposition of basic volcanic rocks.

A later classification of the chlorite group by G. Tschermak[2] bears a general resemblance to the foregoing, his orthochlorites and leptochlorites corresponding respectively with the chlorites and saponites of Heddle.

The chlorites under discussion in this paper naturally fall into the second subdivision, i.e. leptochlorites or saponites. Some chlorites in

[1] M. F. Heddle, Chapters on the mineralogy of Scotland. VI. Chloritic Minerals. Trans. Royal Soc. Edinburgh, 1879, vol. 29, p. 55; Min. Mag., 1880, vol. 4, p. 45.

[2] G. Tschermak, Sitzungsber. Akad. Wiss. Math.-naturw. Cl. Wien, 1891, vol. 100, Abt. I, p. 29.

Derbyshire have already been noticed and described by H. C. Sargent[1] and C. S. Garnett[2]; and the present paper, although quite independent, proceeds along the same line of investigation. It deals mainly with a chlorite found in a decomposed basalt of Calton Hill, the remaining chlorites associated with the upper and lower lavas of Derbyshire receiving but a cursory description for the purpose of comparison.

Calton Hill (4 miles from Buxton on the Buxton–Bakewell road) was opened up some few years ago as a road-metal quarry, with the result that a most interesting geological section became exposed. Only a very brief account of this will be given here, as it will form the subject of a separate paper in the near future. In this section the compact and fresh basalt (quarried for road-metal) is seen to invade an extremely decomposed vesicular basaltic lava ('toadstone') as well as the underlying stratified volcanic agglomerate and tuff. In places the decomposed lava still rests on the upper surface of the stratified pyroclastic material, but deeper down in the quarry the compact basalt has apparently been intruded along the junction of the lava and the tuffs, and has broken off and caught up large masses of the decomposed lava in its midst. There are several of those large 'xenolitic' masses in the compact basalt.[3]

The decomposed basalt varies in colour from chocolate-brown to light brown shot with green. In places where it has been more exposed to weathering it is quite earthy and crumbles easily between the fingers. Under the microscope, this decomposed rock appears as a confused aggregate of chloritic material together with some specks of iron oxide and calcite. The original texture, looking like a well-erased palimpsest, only becomes visible under the crossed nicols. The felspar microlites, probably the last mineral to be affected by the process of decomposition, can be clearly observed under the crossed nicols. They are very turbid with ragged edges, but many of them still show the original twin-lamellae and give almost straight extinction, a fact which suggests that the original felspar was of an alkaline variety, probably an oligoclase. The remaining ferromagnesian minerals are completely decomposed, but sometimes one can see clearly the outlines of a former olivine phenocryst.

[1] H. C. Sargent, On a spilitic facies of Lower Carboniferous lava-flows in Derbyshire. Quart. Journ. Geol. Soc. London, 1918, vol. 73 (for 1917), p. 11.

[2] C. S. Garnett, On a peculiar chlorite-rock at Ible, Derbyshire. Min. Mag., 1923, vol. 20, p. 60; The 'toadstone-clays' of Derbyshire. Min. Mag., 1923, vol. 20, p. 151.

[3] The occurrence of a decomposed lava entrapped in a fresh olivine-dolerite sill at Ible, near Matlock, has been already recorded by C. S. Garnett (loc. cit.), and it may be possible to compare this occurrence with that of Calton Hill.

Comparison of sections of this rock with sections of the decomposed spilitic basalt lava (the base of the upper lava at Knot Low) leads to the conclusion that it represents essentially the same rock, but in various stages of decomposition.

The decomposed basalt is highly vesicular, and the vesicles, which are more or less evenly distributed throughout the rock, are completely filled with a dark chloritic mineral. The latter, much more compact

Fig. 1. Fig. 2.

Fig. 1. Micro-section of chlorite, spherulites in groundmass, from Calton Hill, Derbyshire. Crossed nicols. ×100.

Fig. 2. Micro-section of chlorite, filling a vesicle and partly replaced by calcite, from Miller's Dale, Derbyshire. ×25.

than the rock in which it is embedded, can easily be separated by hand in the form of almond-shaped or nut-shaped nodules. At first sight the rock resembles a volcanic tuff with devitrified glassy lapilli embedded in it. Several blocks of decomposed lava containing abundant vesicular infillings were carefully crushed by hand and the chloritic nodules separated from the groundmass. The weight of each portion was separately determined and the following proportions were obtained: chloritic nodules 12·89, decomposed basalt 87·11, total 100·00. The specific

gravity of the whole rock (groundmass + chlorite) is 2·34, and that of the groundmass (including the pore-space) 2·33; several determinations of the sp. gr. of the chlorite ranged from 2·386 to 2·396, giving an average of 2·393.

The chloritic nodules from the rock were afterwards graded according to size, and the number in each grade was counted. The result was a typical frequency distribution curve with a maximum at 0·6 mm. approximately, and with a sharp slope towards zero and a more gentle one in the opposite direction. This gives some idea of the size of the blow-holes of which the nodules are the exact casts, and of their distribution in the lava. The nodules show a great variety in shape, those of the larger size being more irregular, those of the average size (2–10 mm.) almond-shaped, and those of the smallest size (below 2 mm.) spherical. There were also others dumb-bell shaped.

The colour of chlorite is dark green, passing to light green on the surface of the nodules, and bluish-green along cracks. The hardness is slightly over 2. Streak pale green. Greasy feel. Infusible before the blowpipe. Soluble in hydrochloric acid with the separation of flocculent gelatinous silica.

Under the microscope, the chlorite is pale green, and appears as an aggregate of fibrous spherulites (usually not complete) embedded in a fine groundmass also consisting of spherulites and sheaves of fibres, but of a much smaller size (fig. 1). Between crossed nicols fine second-order colours are shown. The fibres give straight extinction with positive elongation. Pleochroism is very weak or altogether absent. The refractive index of the aggregate (determined by the method of immersion, in sodium-light) was found to be $1{\cdot}563 \pm 0{\cdot}003$.

The mineral was subjected to chemical analysis with the following results:

	Weight %.	Molecular %.	
SiO_2	35·92	26·28	26·28
TiO_2	nil	—	—
Al_2O_3	12·20	5·25	7·34
Fe_2O_3	7·59	2·09	
FeO	4·66	2·85	28·08
MgO	21·82	23·80	
CaO	1·82	1·43	
CO_2	0·13	—	—
H_2O at 105°	6·50	15·86	38·30
H_2O ignition	9·20	22·44	
	99·84	100·00	

The following approximate formula is derived from this analysis:

$$13H_2O \cdot 10R''O \cdot 2{\cdot}5R'''_2O_3 \cdot 9SiO_2,$$

or, disregarding the water lost at 105° C.:

$$7{\cdot}5H_2O \cdot 10R''O \cdot 2{\cdot}5R'''_2O_3 \cdot 9SiO_2.$$

It is obvious that according to its chemical composition this chlorite may be placed in the group embracing such minerals as delessite, diabantite, ripidolite, berlauite, &c. Nevertheless, it differs from these minerals in certain respects, viz. its lower specific gravity and the absence of pleochroism. In its specific gravity it stands somewhere between the delessite-diabantite group and the saponite group. In certain respects it may be well compared with certain varieties of saponite, such as 'bowlingite' and 'cathkinite'.[1] All these leptochlorites are typical 'colloform' minerals and probably pass by imperceptible gradations into one another. The degree of hydration is probably one of the principal factors regulating their morphological characters and their specific gravity, but the latter is also a function of the relative proportion of the heavier metallic oxides. Arranging in the following table certain minerals belonging to the group (serpentine and chlorophaeite being also added for comparison) according to the increasing proportion of water, we notice a gradual decrease in the specific gravity. The position of the Calton Hill chlorite is clearly seen in this table. Without introducing a new mineral name we may simply call it a variety of delessite.

Mineral.	Locality.	Author.	Sp. gr.	H_2O (+ R_2O).	R''O.	R'''_2O_3.	SiO_2.
Serpentine	(theoretical formula)		2·20–2·70	9	13·5	—	9
Diabantite	(theoretical formula)		2·80	9	12	2	9
Chlorite (no. 3)	Ible	Garnett	2·52	9	10	2	9
Chlorite	Darley Dale	Garnett	2·79	10	11	2	9
Ripidolite	Cape Wrath	Heddle	2·823	12	12	3	9
Delessite	St. Cyrus	Heddle	2·652	12	13	2·5	9
Chlorite	Calton Hill	Tomkeieff	2·393	13	10	2·5	9
Griffithite	California	Larsen & Steiger	2·309	13	8	1·5	9
Delessite	Dumbuck	Heddle	2·598	14·5	12	3	9
Berlauite	Berlau	Schrauf	—	15	11	2·5	9
Saponite	Perthshire	Heddle	2·235	18	10	1·5	9
Chlorophaeite	Dalmahoy	Campbell & Lunn	1·81	27	5	2	9

[1] M. F. Heddle, The Mineralogy of Scotland, 1901, vol. 2, p. 139.

Chlorites occurring in vesicles of lavas at other localities in Derbyshire.

The upper lava of Derbyshire is well exposed in Miller's Dale, where the limestone quarries in some places facilitate its study. Both the upper and the lower portions of this lava are extremely vesicular, and the latter was identified by Sargent as a spilite. In his paper (loc. cit.) dealing with spilites, Sargent also mentions some of the minerals occurring in the vesicles, including a fibrous chlorite. Examination of a section of this rock, from Knot Low, shows that, besides a great deal of rather turbid chloritic material in the groundmass, there is also a quite distinct, well-crystallized fibrous chlorite filling up the vesicles. In many places this chlorite is replaced by other minerals, such as calcite or quartz. As already mentioned, this rock is somewhat similar to that of Calton Hill, but is in a less advanced stage of decomposition.

The upper vesicular portion of the upper lava, as occurring in the limestone quarry to the south of the railway line, is quite different from that of Knot Low. It is light grey in colour, and apparently greatly calcified (the rock immediately above it is a limestone). Numerous lath-shaped felspars (oligoclase ?) are embedded in a semi-aphanitic groundmass, mainly composed of a dark green chlorite. Vesicles are filled with secondary calcite (chalcedony in places), but some of them still preserve the original chloritic infilling. This chlorite is dark green in colour with a dull lustre and hardness 2–3. Only very small fragments of this chlorite could be scraped out from the vesicles, but even in the purest of them one could detect the presence of calcite. After a short treatment of one of these fragments with cold hydrochloric acid, the specific gravity was determined by means of heavy liquids as 2·538. This figure may be somewhat too high owing to the presence of some calcite within the chlorite. An attempt was then made to determine the approximate amount of water. The results, expressed in round figures, are : H_2O at 105° C. 10 %, H_2O lost on ignition 20 %, total 30 %. Even taking into consideration a certain loss on ignition due to CO_2 derived from the calcite present in the chlorite, this still represents a high percentage of water.

Under the microscope, this chlorite appears much darker than the Calton Hill chlorite and possesses a totally different structure. Even under a low-power objective one can see clearly that it is formed of an aggregate of bacteria-like bodies imbedded in a semi-amorphous (cryptocrystalline ?) groundmass (fig. 2). Under a high-power objective the structure of these bacteria-like bodies is seen to consist of an elongated,

sometimes dumb-bell-shaped core, composed of granular semi-amorphous green material, and surrounded by a layer of a fibrous white mineral (fig. 3). The groundmass is also composed of a similar granular stuff, together with very minute radiating anisotropic clusters of spherulites. The microstructure of this chlorite is somewhat similar to that of the chlorophaeite from Dalmahoy Hill near Edinburgh, described by R. Campbell and J. W. Lunn,[1] though the individual bacteria-like bodies in our chlorite are much larger than in the Dalmahoy Hill specimens. This fact and the large amount of water present, suggest that we have here a chlorite which, although not a typical chlorophaeite, may belong to the same group. The white fibrous mineral may be some variety of zeolite.

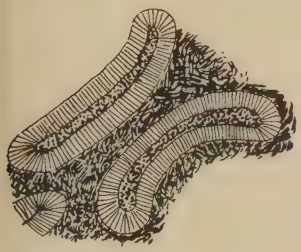

Fig. 3.

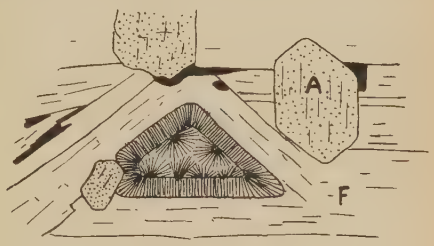

Fig. 4.

Fig. 3. Chlorite from Miller's Dale. Enlargement of bacteria-like bodies in fig. 2. ×130.

Fig. 4. Palagonite from Miller's Dale, infilling spaces between felspar (*F*) and augite (*A*). ×330.

Similar chlorite with a well-defined bacteria-like structure was also observed filling the vesicles of the top portion of the lower lava at Ravens Tor, near Miller's Dale.

Both the upper and the lower portions of the lava are affected by weathering. However, it was possible to obtain a fresh specimen of this lava from the middle portion, of which the outcrop can be found in some old disused quarries near Miller's Dale. In these the basalt weathers spheroidally and some of the cores of the spheroids are composed of compact dark grey basalt. Under the microscope, this basalt appears to be quite fresh, with the exception of olivine, which is completely serpentinized. Felspar apparently exists in two generations: felspar-laths (labradorite) and a more acid allotriomorphic felspar of a later stage of

[1] R. Campbell and J. W. Lunn, Chlorophaeite in the dolerites (tholeiites) of Dalmahoy and Kaimes Hills, Edinburgh. Min. Mag., 1925, vol. 20, p. 435.

crystallization. Augite is present in the form of semi-idiomorphic granules, and iron-ore in the form of granules and rods. All lacunae between the felspar-laths and augite-grains are occupied by a certain amount of allotriomorphic felspar of the second generation and by a large quantity of a light brownish-green mesostasis. In certain places this mesostasis is seen to pass into, or encroach upon, the felspar of the second generation. This mesostasis consists entirely of anisotropic material in the form of a fibrous spherulitic aggregate, somewhat similar to the chlorite of Calton Hill. It is non-pleochroic, gives straight extinction along the fibres, shows bright polarization colours, and has a refractive index higher than Canada balsam. The walls of every lacuna are lined with a fibrous layer of this mineral, and a more or less irregular spherulitic aggregate fills up the remaining space (fig. 4). In places it is interpenetrated by rods of iron-ore. There is but little doubt that this substance is the so-called palagonite.

D. N. Wadia, in his work on a palagonite-bearing dolerite, states the opinion, 'that palagonite is not a definite mineral, but an amorphous decomposition product of variable composition formed *in situ* within the rock'.[1] He also found that in this particular rock palagonite was formed not only at the expense of glass alone, but also as a product of decomposition of the ferromagnesian constituents. In our case, however, all augite is perfectly fresh, as also the iron-ore. The palagonite of the Miller's Dale basalt must be, therefore, either the product of alteration of the original glassy mesostasis, or an autogenous product formed from the hydrated residual liquor during the final stages of the crystallization of the magma.

L. L. Fermor, in his most interesting work on Deccan basalts, has described many varieties of palagonite and secondary chlorite, and is of the opinion that the great part of the palagonite in the Bhusawal traps represents the original glassy mesostasis which has become devitrified and transformed into an aggregate of chlorites (delessite or diabantite).

'Treated generally, palagonite may perhaps be regarded as a hydrous glassy substance of variable composition formed partly by hydration of the primary glass and partly at the expense of augite (? again largely hydration) and iron-ore, and with much more difficulty at the expense of felspar (? by replacement). In colour it ranges through orange and brown to brownish green and bright green, and the material of all colours may become "devitrified" and anisotropic in spherulites and concentric-radiate layers, with in all cases a positive elongation to the fibres. The clear orange and brown varieties, both isotropic and

[1] D. N. Wadia, Palagonite-bearing dolerite from Nagpur: suggestion regarding the nature and origin of palagonite. Rec. Geol. Survey, India, 1925, vol. 58, p. 342.

anisotropic, constitute chlorophæite, whilst the anisotropic green form is probably identical with delessite or celadonite.'[1]

It is quite possible that in many cases the chloritic palagonite may be formed from glass or augite, but there are certain facts which suggest that the palagonite in the Miller's Dale basalt is a primary and not a secondary mineral. As already mentioned, all the augite in this basalt is perfectly fresh and therefore this source of origin is excluded. The palagonite is more or less uniform throughout the rock and not a trace or indication of any original glassy substance is seen. This, together with the presence of a regular radiate layer lining the walls of every lacuna, precludes the possibility that palagonite is a product of devitrification of glass, such as we may observe in many rhyolites and pitchstones. The original glass has either been completely dissolved and redeposited in the form of a fibrous aggregate; or, what the present author thinks to be more probable, the glass has never been formed at all and the palagonite is an autogenous mineral formed during the final stages of the consolidation of the lava.

The external resemblance between the palagonite in the central portion of the upper lava and the chlorite infilling the vesicles at its peripheries (Calton Hill chlorite) suggests that they may be genetically related. The albitization of the peripheral portion of the lava flow and the infilling of vesicles with fibrous chlorite (and in some cases by albite, as mentioned by Sargent) were certainly prior to the intrusion of the compact basalt of Calton Hill (late Carboniferous or Permian), and therefore long before the present agents of weathering came into action. The facts supporting this contention are as follow:

(1) The black compact basalt of Calton Hill is perfectly fresh, while the enclosed lava is greatly decomposed.

(2) Observations of the products of atmospheric weathering of Derbyshire lavas fail to reveal the formation of the finely radio-spherulitic type of chlorite; on the contrary this type of chlorite tends to be destroyed and replaced by an earthy chlorite greatly contaminated by brown hydrated iron oxides. (These lavas on weathering, as was shown by Garnett and also observed by the present author, are gradually losing the ferromagnesian constituents, and pass first into a green clay and finally into a white clay which consists mainly of a hydrous aluminosilicate).

[1] L. L. Fermor, On the basaltic lavas penetrated by the deep boring for coal at Bhusawal, Bombay Presidency. Rec. Geol. Survey, India, 1925, vol. 58, p. 133.

(3) In places where the upper portion of the lava is seen *in situ* below the limestone, there is a tendency for the chlorite infilling the vesicles to be replaced by calcite, quartz, &c., without any formation of secondary chlorite.

(4) Fragments of dark green chlorite, similar to that found in the decomposed lava at Calton Hill and in the vesicles of the upper and the lower lava at Miller's Dale, were found among the stratified tuffs underlying the lava at Calton Hill. These fragments of chlorite were obviously derived from an underlying lava (probably the lower lava) during the volcanic outburst preceding the eruption of the upper lava.

We may surmise, therefore, that the albitization and chloritization of the lava occurred at a later stage in the crystallization of the magma, and the infilling of vesicles soon after its final solidification, probably under the influence of hot magmatic solutions (autopneumatolysis).[1]

The chlorites found in the basaltic lavas of Derbyshire can thus be classified according to their genesis, as follows:

(1) Primary chlorite (palagonite), found in the mesostasis of lavas.

(2) Chlorite of the post-volcanic phase (autopneumatolitic), found infilling vesicles.

(3) Secondary chloritic material, a product of atmospheric weathering, found in abundance in the crust of weathering of lavas and in the green clays resulting from such weathering.

I wish to express my thanks to Mr. H. C. Sargent, who kindly sent me some specimens of the spilitic lavas of Derbyshire, and also to Miss M. Illington, B.Sc., who has assisted me in writing up this paper.

[1] O. O. Baklund (H. G. Backlund), The basalt of Bolshezemelsck tundra, Trav. Musée Géol. Pierre le Grand, Acad. Sci. St. Pétersbourg, 1911, vol. 4 (for 1910), pp. 75–97, has described a chloritic substance occurring in amygdules and mesostasis of a basalt from Siberia. It is dark brownish-green in colour, feebly double-refractive and radial-fibrous in structure. In the mesostasis it can be sharply distinguished from the glass. In its chemical composition it resembles hullite. The author of that paper thinks that it is not a secondary product infilling vesicles, nor a product of alteration of glass, but that its origin could be explained by the assumption that 'the magma after the crystallization of felspar (and augite) has separated into two immiscible portions, so that one of them solidified as glass containing some skeletal crystals of magnetite formed before or simultaneously with the glass, while the remaining portion of the magma, which contained the greater part of the water vapours originally present in the liquid magma, acquired an abnormal composition and solidified in a colloidal state, forming a mixture of hydrogels with some adsorbed oxides' (pp. 93–94). This hypothesis advanced by O. O. Baklund can be offered as another plausible explanation of the genesis of amygdaloidal and mesostatic chlorite in Derbyshire lavas.

On the nature of Berthierite.

By F. L. Stillwell, D.Sc.
Department of Geology, University of Melbourne.

[Read June 15, 1926.]

SIX analyses of berthierite from various localities are quoted by Dana[1] and show a varying composition. The analyses correspond approximately to the formulae $FeS . Sb_2S_3$, $3FeS . 2Sb_2S_3$, and $3FeS . 4Sb_2S_3$. It is considered by Dana that the variation is probably due to the impurity of the analysed material and that the composition of berthierite is probably $FeS . Sb_2S_3$. This view is supported by the examination and analysis of a specimen of berthierite from Nullamanna, 18 miles north of Inverell, New South Wales.

The specimen was kindly lent by Mr. G. W. Card, Curator of the Mining Museum, Sydney, for comparison with certain minerals under investigation, and measured approximately $1 \times 1 \times 0{\cdot}7$ cm. It was sliced and one portion was polished for examination under the reflecting microscope while the other portion was used for the chemical analysis. In the hand-specimen a columnar structure is seen and the colour is dark steel-grey, except for tarnish colours. Like stibnite, it is soft and takes a good polish when polished on a soft flannel or felt.

The polished section proves on examination to be fairly pure except for a certain amount of intergrown stibnite, from which berthierite is not readily distinguished without etching. The colour of the berthierite is bright white and may show a faint tinge of pink in comparison with stibnite. Like stibnite, the colour is slightly variable according to the orientation of the crystals; and in a homogeneous aggregate, some grains possess a shade distinctly more grey or greyish-pink than others, and sufficient to partly reveal the structure of the aggregates. When the reflected light is wholly polarized these changes are stronger and general. This may be observed in a crystal by rotating the stage, and the phenomenon is analogous either to that of general absorption in transmitted light in such minerals as calcite, or to pleochroism.

[1] Dana, System of Mineralogy, 6th edit., 1892, p. 115.

Like stibnite, berthierite shows a marked effect in polarized light with crossed nicols. The section, being parallel to the columnar structure, shows a number of long prismatic crystals, lying with their long axes parallel. In places the prisms are fractured and bent, and some are twinned. The colours are similar to those of stibnite, from which it can be distinguished in this section by the absence of the complex internal structure of stibnite. The structure of the berthierite visible between crossed nicols is shown in fig. 1, where the intergrown stibnite has been darkened by etching prior to photographing.

Berthierite is readily distinguished from stibnite by its behaviour on etching with HNO_3 or with KOH. With HNO_3 of standard strength (1 to 1) stibnite is readily blackened, while berthierite is only faintly affected. A tarnish slowly develops on the Nullamanna berthierite, but at a very much slower rate than on stibnite. A slight tarnish also develops on berthierite upon etching with KCN (20 % solution), and in these two respects the Nullamanna berthierite differs from that recorded by Murdoch [1] and Davy and Farnham,[2] which is negative to all etching reagents except KOH and NaOH.

With a concentrated solution of KOH both minerals are rapidly attacked, but stibnite is immediately covered with a yellow coating, while the berthierite is merely darkened. Berthierite is also darkened by NaOH, while stibnite remains unaffected.

The etching process thus enables a strong contrast to be developed between the berthierite and the stibnite (fig. 2). This photograph represents the same field of view as fig. 1, which, prior to photographing, was etched with KOH and partly re-polished. The internal structure of the prism of stibnite in the photograph is not uniform, but, when polished, is revealed in polarized light as an aggregate of interlocking individuals, some of which show twinning. The differing orientation of these crystals is the cause of varying depths of etching. The more lightly etched surfaces have been cleaned during re-polishing after etching, so producing a speckled appearance on the stibnite in the photograph. The difference between the two minerals is finally demonstrated when a microchemical test for iron is carried out on excavated particles of berthierite and a copious development of Prussian blue is observed microscopically upon addition of a grain of potassium ferrocyanide to the test solution.

[1] J. Murdoch, Microscopical determination of the opaque minerals, 1916, p. 103.

[2] W. M. Davy and C. M. Farnham, Microscopic examination of the ore minerals, 1920, p. 117.

In order to estimate the relative proportions of berthierite and stibnite, the etching process with KOH was used and the yellow precipitate allowed to remain on the stibnite. The amount of the yellow coated mineral was then determined by the Rosiwal micrometric method in the same way as employed in rock sections in transmitted light, and it was found that the amount of stibnite was approximately 16 % of the surface area of the

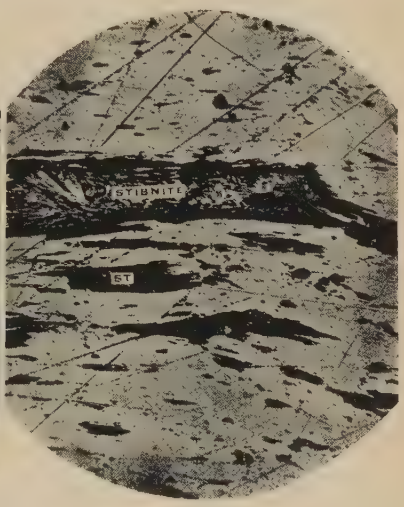

FIG. 1. FIG. 2.

FIG. 1. Polished section of berthierite and stibnite (st), showing parallel arrangement of prisms of berthierite visible between crossed nicols, from Nullamanna, New South Wales. The section has been etched with KOH and sufficiently re-polished to remove all tarnish from the berthierite, so that, in ordinary light, the stibnite (st) appears dark in comparison with the berthierite. Mag. 50 diams.

FIG. 2. Polished section of berthierite and stibnite (st), Nullamanna, New South Wales. It represents the same field of view as fig. 1 photographed in ordinary light. Mag. 50 diams.

polished section. Allowing for the relative densities of stibnite and berthierite, this is increased to approximately 18 % by weight.

Chemical Analysis.—The specimen was analysed by W. A. Grieg in the Mines Department laboratory, New South Wales, and the result is given in column I. The atomic ratios derived from this analysis are given in columns II and III, while column IV is an analysis of berthierite from Bräunsdorf, Saxony, quoted by Dana.

	I.	II.	III.	IV.
Sb	58·63	0·480	8	59·30
Fe	10·08	0·180	3	10·16
S	28·71	0·897	15	30·53
Insol. matter	1·44			—
Water . .	1·14			—
	100·00			99·99

The similarity with the Bräunsdorf specimen is evident on these figures, and it can be inferred that the Bräunsdorf specimen, like the Nullamanna specimen, was contaminated with stibnite. Moreover, the extent of the contamination is practically the same, because both analyses correspond approximately to the formula $3FeS,4Sb_2S_3$.

The actual composition of the berthierite can be estimated by making allowance for the 18 % of stibnite which has been determined microscopically. In the compound $3FeS.4Sb_2S_3$ there is 83·6 % Sb_2S_3 and 16·4 % FeS. Removing 18 % Sb_2S_3, there remains 65·6 % Sb_2S_3 and 16·4 % FeS, which, expressed in percentages, is 80 % Sb_2S_3 and 20 % FeS. The calculated amounts of Sb_2S_3 and FeS in the compound $FeS.Sb_2S_3$ are 79·2 % Sb_2S_3 and 20·8 % FeS. Considering the approximate nature of the Rosiwal determination, these figures seem sufficiently close to indicate that the formula of berthierite is $FeS.Sb_2S_3$.

The association of berthierite with the same amount of stibnite in two such widely separated localities as Bräunsdorf and Nullamanna appears to indicate that an iron sulph-antimonite $3FeS.4Sb_2S_3$ formerly existed during an early stage of the formation of the mineral vein, and that during the later stages this compound dissociated into berthierite and stibnite. In any case it would appear as if the development of the berthierite occurred in the presence of excess antimony sulphide.

The identity of the Cobija and Lampa meteoric stones.

By E. D. Mountain, M.A.
Assistant in the Mineral Department, British Museum (Natural History).

[Read March 16, 1926.]

FROM an examination of thin sections of specimens in the British Museum (Natural History) labelled Cobija and Lampa and also from a consideration of the present distribution of these meteorites in the British Museum and in the Ward-Coonley collection in the Field Museum of Natural History, Chicago, Dr. G. T. Prior thought that there was strong evidence in favour of their identity. In his 'Catalogue of Meteorites' (1923, p. 95) he states with reference to the Lampa stone: 'Except that it is more oxidized, in characters it is very similar to Cobija, and may be identical with it since the information as to locality was obtained not from H. A. Ward but indirectly from the School of Mines, Santiago.' Dr. Prior subsequently handed me these meteorites for a chemical examination.

The Cobija Stone.

The Cobija stone was described by Professor Henry A. Ward,[1] and was acquired by him, during a visit in April 1905, from Professor Julio Laso, the Custodian of the Collections at the School of Mines at Santiago, Chile, who had found the specimen in 1892 on the Pampa of Santa Barbara, east of Cobija, province of Antofagasta. The dimensions of the stone were given as $14 \times 12\frac{1}{2} \times 11$ cm., one side and one end being somewhat flattened, and the original weight as 3,690 grams. The surface is described as dark brown, 'slightly tinged with reddish hue at the more oxidized places', the crust, which covers half the surface, appearing shining or varnished in places. A photograph of a section only is given. This section is roughly the same shape as the slice in the British Museum collection, almost identical in size, and similar in appearance.

There are two specimens of the Cobija stone in the British Museum, an end-piece obtained from H. A. Ward in 1905, which weighed 301 grams,

[1] H. A. Ward, Proc. Rochester Acad. Sci., 1906, vol. 4, p. 229.

and a slice 7 mm. thick, weighing 252 grams, obtained from Mrs. L. A. Coonley Ward in 1907. The white granular patches covering the polished surface would appear to be hollows filled with the polishing powder. Both specimens show in places the reddish-brown shining crust described by Ward, and the other details in his description would also apply.

A fractured surface shows a porous, fine-grained structure coloured brown by iron oxide. A polished surface shows the iron uniformly scattered through the stone in irregular grains together with subordinate troilite. Olivine and pyroxene occur both as irregular chondrules and also as rounded chondrules up to 5 mm. in diameter. A fibrous radiating structure can be observed in some of these latter, but they appear mostly to be granular. These chondrules have broken with the matrix on the fractured surface.

In thin sections, the crystals of olivine and pyroxene are seen to be fresh and well developed and appear as phenocrysts or grains in a groundmass of the nickel-iron, while the felspar forms a fine-grained mosaic or is interstitial in the olivine and pyroxene. The whole section is iron-stained, especially at the margin corresponding to the crust, where there has formed a reddish-brown cement between the crystal grains; in the interior, the crystals of olivine and pyroxene are considerably stained yellow in bands following cracks in the crystals. Small chondrules are fairly numerous both of the lamellar and fibrous forms; while crystalline-granular chondrules are present, but more obscure.

The microscopic section was prepared from the end-piece, and from the same piece some of the freshest material, weighing 14·0375 grams, was selected for analysis. Hydrostatic weighing of the larger specimen gave an uncorrected value of the specific gravity of 3·40. A more accurate determination of the specific gravity made on ten grams of material similar to that analysed, after expulsion of air by boiling, gave 3·580 as the corrected specific gravity.

A magnetic separation of the attracted and unattracted portions gave the following figures:

weight of attracted portion . .	2·3434 grams
weight of unattracted portion . .	11·5174 „
	13·8608

The complete quantitative analysis of this material was carried out on the lines established by Dr. Prior, and I am very greatly indebted to him for his help in manipulation and interpretation of results.

Chemical analysis of Cobija.

	Attracted.	Unattracted.	Bulk.	Unattracted Soluble in HCl.	Unattracted Insoluble in HCl.
Fe... ...	76·61	—	12·95	—	—
Ni... ...	7·30	—	1·24	—	—
Co ...	0·34	—	0·06	—	—
Fe... ...	0·63	4·23	3·68	[4·23]	—
S	0·36	2·42	2·10	[2·42]	—
SiO_2 ...	2·47	43·42	37·06	16·83	26·55
TiO_2 ...	—	0·15	0·13	—	[0·15]
Al_2O_3 ...	—	3·33	2·81	1·20	2·48
Fe_2O_3 ...	—	3·14	2·65	3·19	—
Cr_2O_3 ...	—	0·35	0·30	—	0·35
FeO ...	0·80	10·37	8·83	[6·57]	3·80
MnO ...	—	0·28	0·24	—	0·28
CaO ...	1·78	2·66	2·55	0 80	2·10
MgO ...	1·41	27·39	23·35	17·25	10·07
Na_2O ...	—	0·85	0·72	—	[0 85]
K_2O ...	—	0·17	0·14	—	[0·17]
H_2O ...	—	0·53	0·45	[0·53]	—
Insol. ...	7·65	—	—	—	—
	99·35	99·29	99·26	53·02	46 80

	Molecular proportion.	Cr.	Il.	Fe_2O_3.	Or.	Ab.	An.	Ol.	Pyr.
SiO_2 ...	0.617	—	—	—	6	66	30	221	294
TiO_2 ...	0·002	—	2	—	—	—	—	—	—
Al_2O_3 ...	0·027	—	—	—	1	11	15	—	—
Fe_2O_3 ...	0·017	—	—	17	—	—	—	—	—
Cr_2O_3 ...	0·002	2	—	—	—	—	—	—	—
FeO ...	0·123	2	2	—	—	—	—	77	45
MnO ...	0·003								
CaO ...	0·045	—	—	—	—	—	15	—	30
MgO ...	0·584	—	—	—	—	—	—	367	217
Na_2O ...	0·011	—	—	—	—	11	—	—	—
K_2O ...	0·001	—	—	—	1	—	—	—	—
H_2O ...	0·029								

Mineral composition.

Felspar	Orthoclase	0·56	10·49
	Albite	5·76	
	Anorthite	4·17	
Pyroxene	$CaSiO_3$	3·48	31·12
	$MgSiO_3$	21·70	
	$FeSiO_3$	5·94	
Olivine	Mg_2SiO_4	25·69	33·54
	Fe_2SiO_4	7·85	
	Ilmenite	0·30	
	Chromite	0·48	
	Fe_2O_3	2·65	
	Troilite	5·78	
	Nickel-iron	14·25	
	H_2O	0·45	
		99·06	

The Lampa Stone.

The specimen of the Lampa stone in the British Museum weighs 200 grams and shows a certain amount of the external surface. It was acquired in February 1910 from Dr. C. G. Gilbert, who was left in charge of Ward's collection after his death in 1906.

The stone was described by Professor Farrington,[1] who states the following: 'Among a number of meteorites obtained by the late Professor Henry A. Ward in Chile in 1905, one was placed by Professor Ward in the hands of the writer for description. The only information given the writer by Professor Ward at that time was that the meteorite had been handed to him by some one at the School of Mines at Santiago. On corresponding with the School of Mines, the Director, Señor A. Orrego Cortes, kindly informed the writer that the meteorite had been found in the Sierra de Chicauma, near Lampa.' Cortes also informed him that a further 5–6 kilograms had been preserved. The stone received by Ward from Santiago measured 10×15 cm., but only a part of this, in two pieces, weighing 2·8 kilograms, was handed on to Farrington. Two photographs of these pieces are given. No mention, however, is made either of the date on which Farrington obtained the stone or as to whether the whole was returned to Ward after examination.

A recent letter from Professor Farrington gives a slightly different impression. He writes: 'For my account of Lampa I relied on the information given me verbally by Professor Ward, which seemed to be fully confirmed by the letter of Director Cortes. Professor Ward's death occurred soon after he had handed me the meteorite for description, so that there was no opportunity for further inquiry of him as to details of the transaction by which he secured the meteorite.'

With reference to the Lampa stone Dr. Gilbert wrote in a letter to Sir L. Fletcher that the 'record had been mislaid by Professor Ward and become completely obscured temporarily owing to his sudden death'. As it seemed possible that the specimen sent by Dr. Gilbert might not be a specimen of the stone described by Farrington, it was thought desirable to compare it with the original Lampa. Professor Farrington has kindly forwarded a piece weighing 555 grams for this purpose. It is the portion shown in the lower part of the photographs accompanying his description and is identical in character with the specimen sent by Dr. Gilbert.

[1] O. C. Farrington, Field Columbian Mus. Chicago, 1907, Publ. 122, Geol. Ser., vol. 3, no. 6, p. 115.

Farrington's description of the meteorite is not inapplicable to the Cobija stone, except for a system of cracks on part of the surface and other physical characters of the crust. The interior is compact and chocolate to reddish-brown in colour. The specific gravity, determined on a piece weighing 557 grams, was given as 3·4005.

The stone in the British Museum is an irregular fragment with a considerable amount of crust, which is of a reddish shiny appearance, and also possesses a system of cracks, which, however, scarcely penetrate into the stone. The interior on a fractured surface resembles the Cobija stone, but is of a more reddish-brown tint. Other physical characters and the microscopic appearance of a thin section agree with Farrington's description. Apart from a slightly deeper staining of the crystals by iron and the system of iron-stained veins at the surface, no distinction can be drawn from that of Cobija.

Hydrostatic weighing of the whole piece gave an uncorrected specific gravity of 3·45, while 11 grams of the least altered material, after removal of air-bubbles, gave a specific gravity of 3·572. An amount of 12·2854 grams of the best material was collected for analysis, and, after crushing and separating with the magnetic comb, gave the following results:

weight of attracted portion . . .	2·0062 grams
weight of unattracted portion . .	10·0838 ,,
	12·0900

A partial chemical analysis gave the following results:—

	Attracted.	Unattracted.	Bulk.	Unattracted Soluble in HCl.	Unattracted Insoluble in HCl.
Ni + Co ...	7·58	—	1·26	—	—
SiO_2... ...	—	42·96	36·44	15·40	27·43
Al_2O_3 ...	—	3·75	3·18	1·51	2·24
Fe_2O_3 ...	—	5·66	4·80	6·13	—
FeO	—	10·30	8·74	[6·29]	4·01
CaO	—	2·58	2·19	0·85	[1·73]
MgO... ...	—	27·27	23·13	16·05	[11·22]
Insol. ...	7·30	—	—	—	—

For convenience, the following characters are further listed together to show the similarity between the two stones:—

	Cobija.	Lampa.
Specific gravity (of mass)	3·40	3·45
Specific gravity (selected material) .	3·580	3·572
Percentage of nickel-iron	14	—
Ratio of iron to nickel	$10\frac{1}{2}$	—
Ratio of MgO to FeO (in olivine) .	$4\frac{1}{2}$	$4\frac{1}{2}$
Ratio of MgO to FeO (in pyroxene)	5	5

These meteorites, then, both belong to the Ck group of Brezina and to the Cronstad type of Prior.

It will be noticed that the specific gravity of Cobija determined on a large mass is identical with the value given by Farrington for Lampa determined in a similar way.

It is curious that, if Ward obtained the Lampa stone in 1905, no mention was made of it in his account of Cobija, and also that Farrington in 1907 made no reference to Ward's account (published in 1905) of the meteorites obtained by him. The dimensions of the respective stones are, moreover, almost identical and the weights given are quite compatible. It is also a curious coincidence that the section shown in perspective in Farrington's paper is almost identical in size, though not in shape, with the section of Cobija in Ward's paper, and also with the section of Cobija in the British Museum.

A consideration of the distribution of these stones at the present time leads to rather interesting results :

	Cobija.	Lampa.
Chicago[1]	1,100 grams	886 grams
	120 „	555 „
British Museum . . .	301 „	220 „
	252 „	
Total known at present	1,773 „	1,661 „
Original weight . . .	3,690 „	2,800 „

The figure for the total weight (3,434 grams) of both stones, now in Chicago and London, falls short of the original Cobija weight, though only by 256 grams. If Farrington had 2·8 kilograms and definitely established them as Lampa, what has subsequently become of the rest weighing 2·2 kilograms? In his paper, Ward states that of the 3,690 grams, the original weight of Cobija, the largest piece, weighing 1,805 grams, was retained in the Ward-Coonley collection. This is comparable with the 1,773 grams for the total of the Cobija now identified. In a letter from Ward to Sir L. Fletcher in 1905 he says, with reference to the Cobija stone, 'I took it to cut and to send back half, which I did'. Unfortunately, I have been unable to ascertain whether any of the original Cobija is now in the School of Mines at Santiago.

The foregoing account supports Dr. Prior's conclusion that the only difference between the two meteorites is the more oxidized condition of

[1] O. C. Farrington, Catalogue of the Collection of Meteorites, 1916. Field Mus Nat. Hist. Chicago, 1916, Publ. 188, Geol. Ser., vol. 3, no. 10.

the Lampa stone, though satisfactory information as to the original locality of these stones is still lacking. Our knowledge, moreover, of the present distribution of these stones is very incomplete. Cobija and Lampa are situated 750 miles apart, so that there is no possibility of these localities being those of two stones of the same fall. The evidence suggests that Ward obtained two separate specimens of Cobija from the School of Mines at Santiago in 1905, but that one, which was subsequently described on insufficient evidence by Farrington as the Lampa stone, was mislaid at the time of his describing Cobija.

Sperrylite crystals from the Transvaal.

By L. J. Spencer, M.A., Sc.D., F.R.S.
Assistant-Keeper in the Mineral Department, British Museum (Natural History).

[Read June 15, 1926.]

A VERY fine and unusual crystal of sperrylite, recently presented by Mr. G. H. Beatty of Johannesburg to the mineral collection of the British Museum, came from a new adit on the Tweefontein farm (no. 1033), about 10 miles NNW. of Potgietersrust, Waterberg district, Transvaal. It had been found embedded in copper-stained limonite in crush-zones of banded ironstone underlying norite. The limonite matrix is presumably an alteration-product of sulphides (pyrrhotine, pentlandite, and chalcopyrite). The banded ironstone is an altered sediment belonging to the dolomite series, and is penetrated by apophyses from the basic margin of the Bushveld igneous complex.[1]

The crystal measures 5·5, 5·3, and 5·0 mm. in the direction of the three cubic axes and weighs 1·294 grams. It is thus far larger than any sperrylite crystal from the few localities[2] previously known for this

[1] An account of the platinum occurrence at this locality has been given (previous to the finding of the sperrylite) by P. A. Wagner, Trans. Geol. Soc. South Africa, 1926, vol. 28 (for 1925), p. 110. [Min. Abstr., vol. 3, p. 76.]

[2] (1) In copper-nickel ores from the Vermilion mine, Denison township, Sudbury district, Ontario (H. L. Wells, 1889); also in chalcopyrite from the neighbouring Victoria mine (C. W. Dickson, 1903).

(2) In ruby-bearing gravel of tributaries (Caler Fork and Mason Branch) of the Little Tennessee River, near Franklin in Macon Co., North Carolina; also in sand near the summit of Mason Mountain in this district (W. E. Hidden, 1898).

(3) In covellite from the Rambler mine, Medicine Bow Mountains, Wyoming (H. L. Wells and S. L. Penfield, 1902).

(4) Nikolaevsky gold-washings on the Timpton river, a tributary of the Zeya in prov. Amur, eastern Siberia (P. P. Pilipenko, 1915). [Min. Abstr., vol. 2, p. 138.]

(5) A mention of sperrylite from British Columbia has not been verified in the literature.

The size of the Ontario crystals is given as 0·05 to 0·5 mm.; one measured by W. Nicol and V. Goldschmidt (1903) was 0·8 mm. across Crystals from

rare mineral (platinum arsenide, $PtAs_2$). Larger, but imperfect and broken, crystals up to half an inch across have recently been found at this locality in the Transvaal. The specific gravity of the crystal, as determined by hydrostatic weighing, is 10·609 (corrected $D_4^{19.5} = 10{\cdot}58$).

The crystal has a brilliant metallic lustre with silver-white colour, much resembling the crystals of amalgam (silver-amalgam) from the Palatinate (Rhenish Bavaria). It is completely developed on all sides without any point of attachment. Thin films of limonite are present as a few spots on the surface.

The form is the cubo-octahedron with the corners and edges much rounded, and the faces have curved outlines. The rounded areas when examined with a magnifying lens show numerous small but curved facets. Pyritohedral symmetry is not evident. On the goniometer, single sharp images are given by the six cube {100} and the eight octahedron {111} faces. The other areas give a profusion of scattered images, few of which appear to lie in definite zones on the crystal. In the principal zones the only faces identified with certainty are those of the rhombic-dodecahedron {110} and the tetrakis-hexahedron {210} (or the two pyritohedra {210} and {120}). Only one sharp image was obtained for the trapezohedron (icositetrahedron) {211}. Nine of the twelve possible faces of the rhombic-dodecahedron are present as minute facets. The form {210} considered as a pentagonal-dodecahedron is represented by only seven of the possible twelve faces; of these the faces (210) and (021) are of fair size and readily recognizable with a lens, but (102) is absent. Similarly, {120} as a hemihedral form is represented by only seven minute facets, two of which lie about one degree of arc from the true position. This crystal alone cannot help to decide whether the symmetry is holohedral or hemihedral (pyritohedral).

Eleven zones were measured on the Fuess single-circle goniometer, viz. [100], [010], [001], [110], [1$\bar{1}$0], [$\bar{1}$01], [01$\bar{1}$], [12$\bar{1}$], [$\bar{1}\bar{1}$2], [12$\bar{0}$], and [111]. Many faint images and bands of reflected light lying in or very near these zones were noted, but when plotted on a projection they showed no symmetrical repetition. Many other images were out of zone. By measuring such a crystal on a two- or three-circle goniometer it would no doubt be possible to place on record for sperrylite numerous 'new' crystal-forms with high indices. But no useful purpose can be served by recording a number of indefinite faces. The rounding of the edges and

North Carolina are still smaller, for of those measured by S. L. Penfield (1898) 55 weighed only 0·0019 gram. The Transvaal crystal now described is over thirty-seven thousand times as large.

corners of this crystal is very similar to that so well known on diamond crystals; but whether it is due to growth or corrosion of the crystal is not clear. On one of the cube-faces there are well-marked 'terraces of growth'.

A brief preliminary account of the sperrylite crystals from this locality was given by Mr. G. H. Beatty at a meeting of the Chemical, Metallurgical and Mining Society of South Africa on February 20, 1926,[1] and by Dr. P. A. Wagner at a meeting of the Geological Society of South Africa on March 29, 1926.[2] The latter states that the crystals are usually cubic in habit and range from 0·05 to 0·675 inch across, the largest weighing 1·5 oz. troy.

Sperrylite had previously been found in the Transvaal on the Vlakfontein farm (no. 902), about 30 miles NW. of Rustenburg in the Rustenburg district,[3] where, in 1923, minute specks of the mineral were obtained by panning the oxidized sulphide nickel ore. It has also been recently found on the farms Sandsloot (no. 276)[4] and Zwartfontein (no. 121),[5] adjoining the Tweefontein farm in the Potgietersrust platinum field.

Since the above was printed, Mr. George H. Beatty has very kindly brought to the Museum, as a handsome donation from the Chairman and Directors of the Potgietersrust Platinum Mining Company, the largest crystal of sperrylite that has been found at the Tweefontein locality. This crystal is of the same type as that described above, but considerably larger, weighing 33·75 grams (or more than an ounce—either troy or avoirdupois) and measuring $18\frac{1}{2} \times 16\frac{1}{4} \times 15$ mm. along the cubic axes. The greatest diameter, along a dodecahedral (diad) axis, is $22\frac{2}{3}$ mm., or nearly one inch. It is a cubo-octahedron with rounded edges and corners, and shows, in addition to six cube-faces and eight octahedron-faces, one well-defined face of the form $\{210\}$. The development is somewhat irregular, owing to the variable size of the faces. With the

[1] Journ. Chem. Metall. Mining Soc. South Africa, 1926, vol. 26, p. 183.

[2] Report of meeting in South African Journ. Mining & Engin., 1926, vol. 37, p. 124, and Mining Mag. London, 1926, vol. 34, p. 379; to appear also in Proc. Geol. Soc. South Africa for 1926.

[3] P. A. Wagner, On magmatic nickel deposits of the Bushveld complex in the Rustenburg district, Transvaal. Mem. Geol. Survey, South Africa, 1924, no. 21, p. 100 [Min. Abstr., vol. 3, p. 44]. Also mentioned in Trans. Geol. Soc. South Africa, 1926, vol. 28 (for 1925), p. 98 [Min. Abstr., vol. 3, p. 75].

[4] P. A. Wagner, Trans. Geol. Soc. South Africa, 1926, vol. 28 (for 1925), p. 117.

[5] Mentioned by P. A. Wagner, South African Journ. Mining & Engin., 1926, vol. 37, p. 124; Mining Mag. London, 1926, vol. 34, p. 380.

silver-white colour and brilliant metallic lustre the faces give mirror-like reflections. The surfaces are, however, not perfectly smooth: when examined in the reflecting position with a lens all the faces show beautiful 'terraces of growth'. In two places the crystal is slightly broken, showing a well-marked conchoidal fracture and also very good cleavages parallel to the faces of the cube. Attached to the crystal is a small amount of limonite on which is a speck of green copper stain.

Of interest is the piece of friable cellular (gossany) limonite from which this crystal was taken: it shows a sharply marked cavity into which the crystal fits. This comparatively small ($5 \times 4 \times 3$ cm.) piece of limonite also shows portions of two other similar cavities from which large crystals of sperrylite have been taken. At the surfaces of contact with the sperrylite, the limonite is smooth and glazed. Another specimen shows minute specks and small splashes of sperrylite in a more compact matrix consisting of a mixture of limonite, malachite, quartz, and felspar. This no doubt represents a mineralized pegmatite.

A much smaller crystal of sperrylite from this locality, which was sent by Dr. A. W. Rogers for the Cambridge Mineralogical Museum, shows a more perfect development of many small faces, and, as is generally the case with small crystals, this would be more suitable for goniometric measurement and identification of crystal-forms than the show crystals now described.

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